# The Effect of Increased Biomass Size on the Hydraulic Conductivity of a Bioreactor

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## Denitrifying Bioreactors

The hypoxia that exists at the outflow of the Mississippi River into the Gulf of Mexico is a problem attributed, in part, to the increased use of fertilizers in the Midwest[1]. The rise of fertilizer use is a repercussion of the goal to maximize agricultural production. Nitrogen (N) is a main component in fertilizer. Several researchers note that this increase in fertilizer has caused an upturn in nitrate-N run-off[1, 2, 3]. Denitrifying bioreactors are an effective and useful technology in removing nitrate-N from agricultural run-off before it flows into tributaries. Bioreactors address the nitrate-N pollution problem caused by increased production; an increase needed to sustain population growth. Placing bioreactors in agricultural drainage ditches instead at the edges of fields would make the technology easier to access and maintain.

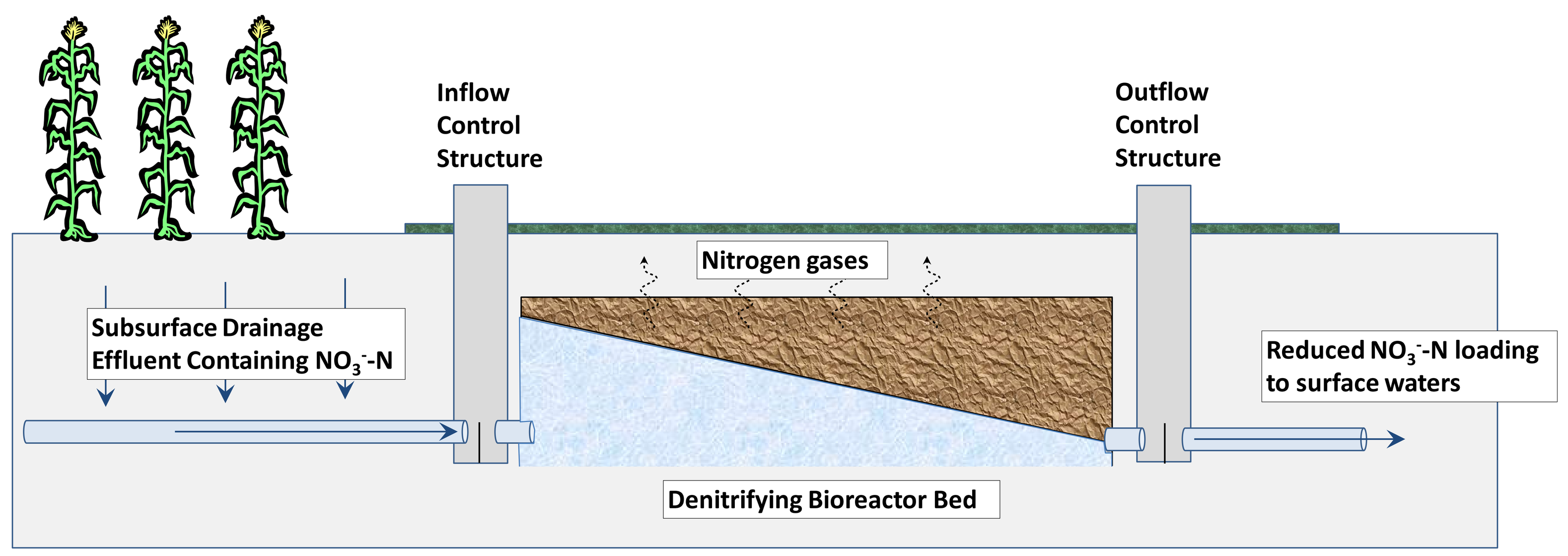


*Figure 1: Design layout of a denitrifying bioreactor*

A denitrifying bioreactor is a practical and cost effective technology that reduces nitrate-N levels in water runoff from agricultural fields (Fig. 1). Tile drainage systems naturally run to drainage ditches. When converted to a bioreactor, ditches are filled with a carbon-based filter medium, into which tile drainage is routed. Anaerobic microbes in the bioreactor bed convert nitrate-N ($NO_3^-$) to nitrogen gas ($N_2$), shown below, reducing outflow loading.

$$5C + 4NO_3^- + 2H_2O \longrightarrow 2N_2 + 4HCO_3^- + CO_2$$

## Identifying Larger Particle Sizes

Bioreactors have been extensively studied. Many variables have been researched in depth or are currently under investigation. One under-tested variable is the biomass particle size. I hypothesized that the conductivity of the bioreactor would increase due to the increased biomass size. Increased conductivity and therefore flow rate increases the potential for bioreactors in drainage ditches due to the increased water quantity and flow distances.

*Figure 2: 1" Mesh Sieve*

I chose to focus my research on the effect of increased biomass size on the permeameter hydraulic conductivity. To investigate, I created a mesh sieve (1" diagonal dimension) to separate acceptable woodchips from smaller chips. All woodchips used were sampled and sent through a particle size distribution to determine the percentage of particles that were greater than 1-in$^2$ (25.4-mm). The distribution also facilitated simpler comparison to previous work.

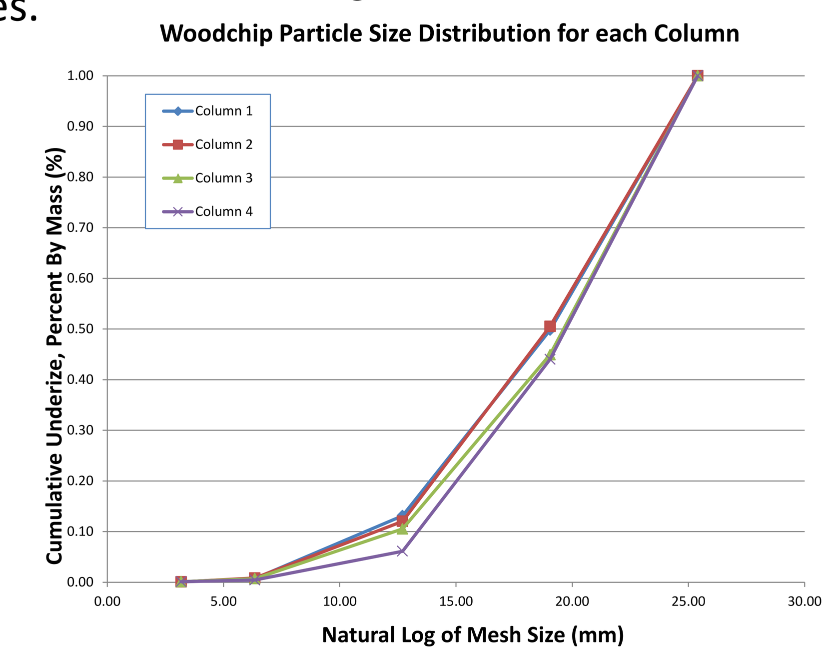


*Figure 3: Particle Size Distribution*

## How the Permeameter Operates

Dr. Gary Feyereisen and his team built a 30-cm diameter by 2.5-m long permeameter over the summer of 2012. This device performs tests on different carbon media types to determine their hydraulic conductivities. It was moved into the BBE South Building on the St. Paul Campus and rebuilt over January 2013.

*Figure 4: Permeameter in vertical position*

To determine the feasibility of drainage ditches and to compare the larger particle size hydraulic conductivity results to previous results, the permeameter was tested in the vertical position (Fig. 4) and in the horizontal position (Fig. 5).

The packing procedure was consistent with previous research and is as follows:

***1.*** Fill a 5 gal. bucket with sieved woodchips, collect a sample, weigh the bucket, pack down each 5 gal. bucket of woodchips into the column using an 8-kg weight and tamp twice.

***2.*** Fill the column with water at a steady pace from the bottom up and let sit for 24-96 hours.

***3.*** Turn on pump, and open outlet water valve to head differences ranging from 0.5-25 cm.

***4.*** Measure flow rates at specific head difference measured by the monometer, a bucket, and stopwatch.

***5.*** Measure porosity: empty water out of column by opening outlet hose, and weighing each bucket.

*Figure 5: Permeameter in horizontal position*

## Methods

The procedure was run a total of eight times: four trials in the horizontal and 4 in the vertical position. The flow velocities, flow rate over the area (Q/A), were plotted as a function of the hydraulic gradient, the change in head over the length (Dh/L). Darcy's Law, k = QL/Adh , was used to calculate the hydraulic conductivity (k). Darcy's flow assumes a linear relationship, however the data is better fit by a power function. To display the relationship more intuitively, the natural log is taken of the flow velocity and the hydraulic gradient (Fig. 6).

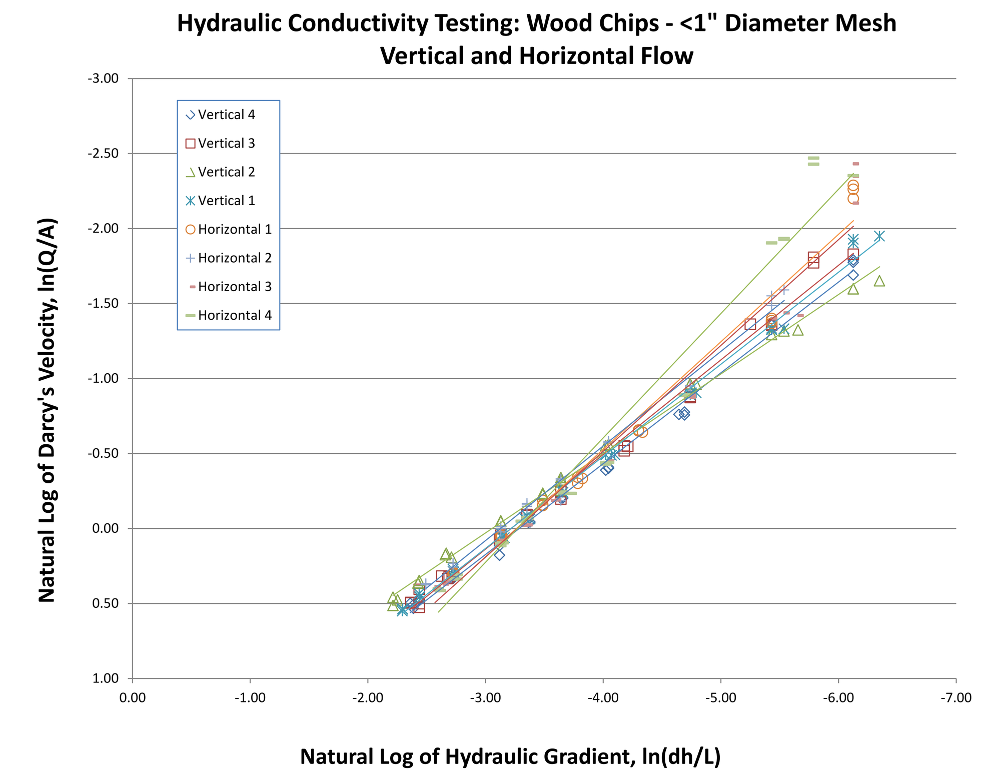


*Figure 6: Graph of hydraulic conductivity of woodchips*

## Results and Discussion

Larger biomass significantly increased the hydraulic conductivity of the permeameter compared to previous trails in both the vertical and horizontal positions. The percent of biomass that was larger than a 25.4-mm mesh was more than 45% larger. Although the error increases when the conductivity is corrected for change in viscosity due to temperature, the hydraulic conductivity is still statistically significant. This is detailed in the table below (Table 1).

*Table 1: Conductivities*

| | Saturated Hydraulic Conductivity, *k*, (cm/s) ± st.dev. | Saturated Hydraulic Conductivity, *k'*, adjusted for water temperature (cm/s) ± st.dev. |
|---|---|---|
| Vertical Average | 6.69 (0.98) b | 8.73 (1.48) b |
| Horizontal Average | 10.68 (3.27) a | 17.23 (5.30) a |
| Feyereisen & Chritianson[4] | 3.02 (0.13) b | 3.28 (0.22) b |

[a] Mean values in a column followed by the same letter are not statistically different at $\alpha=0.10$
[b] Mean values in a column followed by the same letter are not statistically different at $\alpha=0.05$

The large standard deviation for the hydraulic conductivity of the horizontal test could be attributed to:

- Flows inconsistent with the linear model at low flow rates
- Possible open cavities, that could increases flow rate

The dry bulk density and the average flow porosity are much different than the previous data. Larger particles cannot be packed as tightly, leaving more space between them and increasing porosity and lowering dry bulk density, outlined in Table 2.

*Table 2: Material Properties*

| | Mattson | Feyereisen & Christianson[4] |
|---|---|---|
| Dry Bulk Density (kg/m$^3$) | 177 | 220 |
| Average Flow porosity | 51 | 46 |
| Percent Media Larger than 25.4-mm Mesh | 53 | 5 |

## Conclusions

The data collected is promising for the future use of bioreactors in drainage ditches. It is clear that the increased biomass size increased the hydraulic conductivity. Increased hydraulic conductivity is the most crucial factor in moving the system to ditches, to accommodate more flow over a longer distance.

Future research should focus on the type of flow expected in the system from agricultural runoff to see expected results based on flow rates. Another step would be to examine bioreactor holding time and nitrate-N removal in the system with the use of larger biomass.

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